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An
Investigation
Into The
Holding Power
of
Expanded Boiler Tubes.

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The object of this investigation was to determine the holding power of expanded wrought iron boiler tubes at high temperature, such as may be attained in superheaters. Since the experiments were to be made at high temperatures and under as natural conditions as possible for water tube boilers, it was decided to make the tests by closing the ends of the tube by expanding them into suitably designed headers, and subjecting this test piece to internal air pressure. The reason for using air pressure was that at the temperatures that may be attained in superheaters, any liquid with which the test piece could be filled would contain so much stored up energy that rupture of the piece would very probably be followed by a violent explosion, which could not easily be prevented from

doing damage to the apparatus and injuring the experimenter. By using air, the stored up energy and risk of explosion is made a minimum.

From experiments made by H. H. Shock U.S.N. at the Washington Navy Yard, the holding power of expanded boiler tubes at normal temperature had already been determined by pulling off, in a testing machine, the tube plates into which the ends of the tube were expanded. From the results of these tests, for tubes not beaded over, it was decided that an internal pressure of not over 4000 lbs. per square inch would be necessary to push the header off of a 3" tube. Tests of this kind with internal pressure need not be made for tubes that are beaded over, because according to Mr. Shock's experiment, the hot piece ruptures at some point

along its length when beaded, and do not allow the header to pull off at the expanding, and since the end tension in a cylinder subjected to internal pressure is half the circumferential tension, the internal pressure would split the tube instead of forcing off the header. This is also true of most tubes which are expanded with internal ferrules. (See W. H. Stock's "Steam Boilers") In water tube boilers, the tubes are usually neither beaded nor ferruled, and it was for this form of expansion that the following tests were indicated.

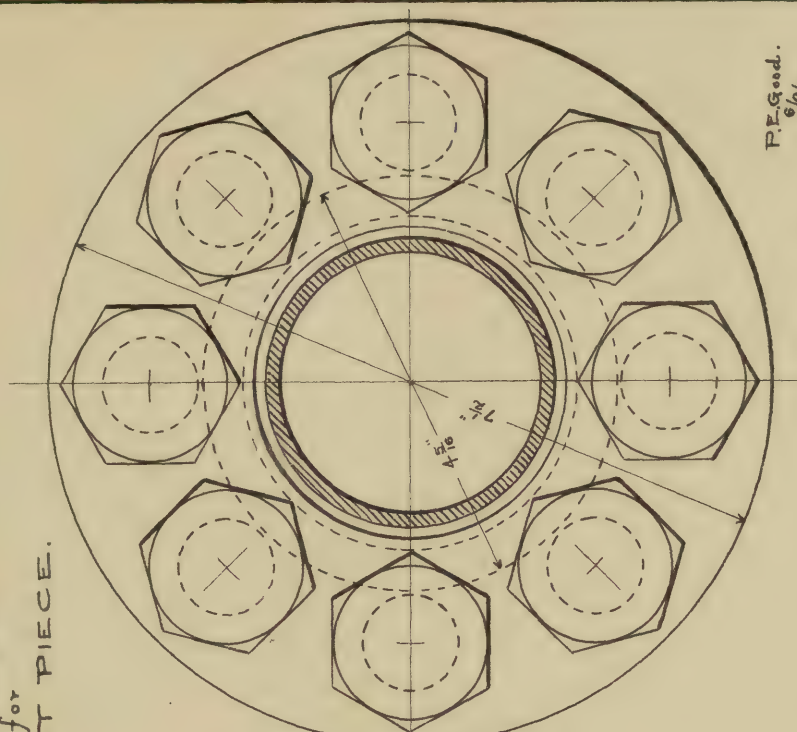
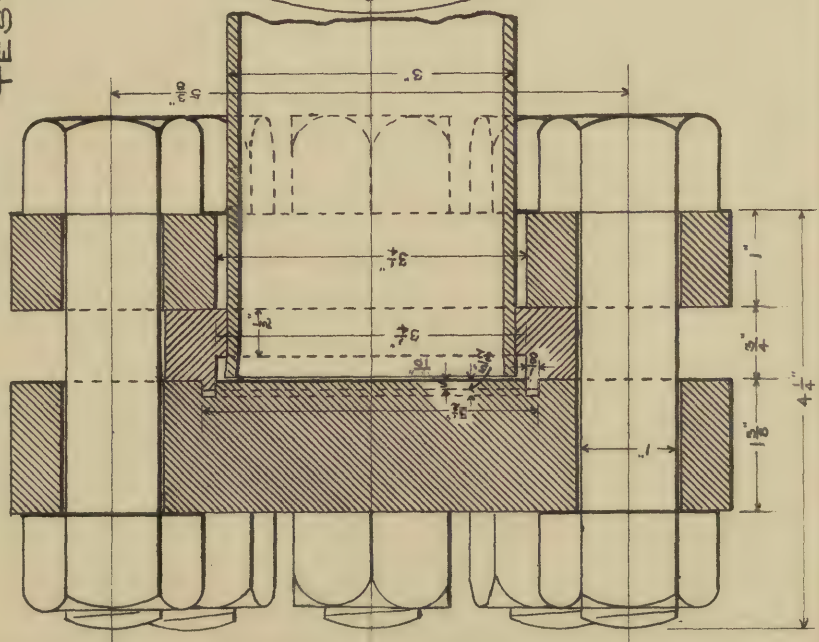
There was available some apparatus that had been used in testing flat plates, this consisting of a hand pump which could produce a pressure (with water or oil) of over 4000 lb per square inch, and a pressure weighing device to be referred to later. To pump air itself to a pressure of 4000

pounds was an impracticability, so it was decided to obtain this pressure by displacing air from a closed chamber by means of water pumped in with the high pressure hand pump. An air compressor capable of pumping to 100 pounds ^{gauge} pressure was also available, and by using it to fill the reservoir with air at 100 pounds, the reservoir necessary for producing a given volume of air at 400 lbs. would be only $\frac{15}{115}$ as large as it would have to be if it were filled with air at 15 lbs. pressure.

The air compressor, the high pressure pump and weighing apparatus and two fine thermometers reading to 1000°F were then the means at hand for doing the work, it being necessary to build the remainder of the apparatus, consisting of air chamber or reservoir, headers and heater for test piece and system of pipe connections.

At first it seemed desirable to make the header of cast iron with inside cover plate, with a ground joint. The excessive thickness of the cast iron required to withstand the high pressure, and the impracticability of keeping the ground joint tight without regrounding it every time that it was to be sealed, as well as the difficulty of expanding the tube through the comparatively small hole that the cover plate could cover led quickly to the abandonment of this idea and the substitution for it of a header made of boiler steel, as shown in the illustration on the following page. A soft copper gasket was now depended on to seal the header, and the ring into which the tube was to be expanded was made separate, and as small as possible, so that it could be easily removed in case it became worn.

HEADER.
for
TEST PIECE.



P.F. Good.
6/9/02.

Scale $\frac{1}{2}'' = 1'$

7.
on the inside, by the tube being pulled out of it. The virtual thickness of the tube plate into which the tube was to be expanded was made one half inch, and space was left in the ring to allow the end of the tube to be flared by the expander. The roller expander was used.

A peculiarity of copper gaskets, for sealing the header, is that the coefficient of expansion with temperature change is much greater for copper than for steel or wrought iron, being in the ratio of 887 to 689 and 640 respectively. For this reason a copper gasket, since the header itself is steel and the bolts wrought iron, will make a tighter and tighter joint as the temperature is increased, but owing to this fact, the gasket is apt to leak when the temperature is lowered, because

of the slight extra crusting of the copper when it tried to expand but could not as the temperature was raised. Soft iron gaskets, if obtainable, would be preferable, but inability to get soft iron wire of the required diameter made the copper gasket a necessity. The gaskets were made of annealed wire, with butt joint carefully filed off so as to butt tightly, and the wire being made as long as would permit of its being forced into the groove in which it was to be embedded. No trouble was experienced in making the gasket tight with a butt joint, whereas a lap joint was found to be a difficult one to fit.

Since soft iron wire was unobtainable of the required size, an attempt was made to substitute for it steel wire, annealed as well as possible. The first gasket

of this kind was tight and never leaked,
 even after having been heated to 1000°
 and cooled again several times. A gasket
 that can be made to be as satisfactory
 as this is a great time and labor saver
 for the experimenter, because a copper gasket
 must be renewed nearly every time that
 the test piece has been cooled down
 from 1000° , and the renewal of gasket
 is not a pleasant operation when it
 has to be done over and over again. Although
 the steel gasket had been so successfully
 used on one header, the attempt to seal
 the other header in the same way was not
 successful, because the only wire obtainable
 was steel, and not capable of being softened
 sufficiently to make it crush down so
 as to fill the bottom of the groove. Soft
 iron wire of the size necessary for this
 purpose (13 or 14 gauge) would be worth consid-

erable trouble in obtaining.

The use a second time of gaskets that had been crushed once, was found to be undesirable because when the copper has been crushed it is hard and brittle and if the crushing is excessive the gasket may not make a tight joint and may be embedded so tightly, and be so hard, that its removal is a very difficult operation, in some cases it having been found necessary to chip it out in small pieces.

In designing the headers, the disc in which the gasket is embedded was considered as being $3\frac{1}{2}$ inches in diameter (this being the external diameter of the gasket) and the thickness was calculated by the formula for circular flat plates carrying uniform load, as found in Merriman's "Mechanics of Materials" p. 330.

$$\text{Thickness} = r \sqrt{\frac{4F}{3T}} \quad \text{where } r = \text{radius in}$$

inches, P = lbs. per square inch pressure, and
 T = allowable unit stress. Using a stress
 of 15000 lbs., this formula gives for the

Thickness: $1.6 \sqrt{\frac{4 \times 4000}{2 \times 15000}} = .953$ inches or
 about 1 inch. The average internal
 diameter of the ring into which the tube
 was to be expanded was approximately = 3.2
 inches. Its minimum allowable thickness
 to enable it to hold 4000 lbs. pressure with
 a stress of 15000 lbs. = $\frac{4000}{15000} \times 1.6 = .427$ "

The ring should therefore be at least
 $\frac{1}{2}$ inch thick.

The groove was made $\frac{1}{8}$ " by $\frac{5}{32}$ ", and the
 projecting ring to be set in the groove was
 $\frac{1}{10}$ " high. This allowed a space of $.056$ "
 $\times \frac{1}{8}$ " sectional area, = $.007$ square inches
 for the gasket. The diameter of wire
 necessary to fill this space = $2 \sqrt{\frac{.007}{\pi}}$
 = $.0944$ " or gauge 13 (B.W.G.). 14 gauge
 was found to answer satisfactorily.

The load carried by the bolts is that due to 4000 lbs. pressure on a circle of $3\frac{1}{4}$ " diam., or load = $\pi (1.6)^2 \times 4000 = 32100$ lbs. According to Kent p. 292, a 1" diameter bolt with Sellers thread, will carry a load of 4150 lbs. with a stress of 10000 lbs. per sq. in. The number of bolts needed is therefore = $\frac{32100}{4150} = 6.21$. Eight bolts were used.

These bolts were found to bind so tightly after heating, that it was impossible to remove them without stripping the thread.

To prevent this, the threads of the bolts and nuts were coated with flake graphite mixed with a little oil. This

prevented binding when put on in ample quantity. Two wrenches with three foot handles were necessary to screw them up.

The smaller the volume inside the test piece and headers, the smaller



can be the volume of the reservoir from which the air must be displaced. Hence the test piece was fitted with a test plug, and to make the latter suitable for two lengths of test pieces, a section 2" long was cut off of one end of this plug, this short section being removed when one end of the test piece had failed and had been cut off and the tube re-expanded into the header. Two discs of $\frac{1}{8}$ " thickness were also provided to fill the space in case the test piece was cut off a little too long, or became elongated due to the expanding.

To find the necessary volume of the reservoir, the space inside the test piece and header not occupied by the plug, had to be found. If the tube and plug are assumed to fit tightly against the cover of the header, the volume in

each header is that of a ring of external radius $1\frac{5}{8}$ ", internal radius $1\frac{1}{2}$ " and of depth $\frac{17}{64}$ ". This volume $= \pi(1\frac{5}{8}^2 - 1\frac{1}{2}^2)\frac{17}{64} = .325$ cu. in. With a clearance of $\frac{1}{32}$ " between ends of tube and plug and the cover of the header, the additional volume $= \pi(1\frac{1}{2})^2\frac{1}{32} = .221$ cu. in.

Total volume of one end $= .325 + .221 = .546$

Total volume of both ends $= 1.092$ cu. in.

Volume needed in reservoir $= \frac{4015}{115} \times 1.092 = 38.1$ cu. in. Make the volume $= 2 \times 40$

$= 80$ cu. in., or 100 cu. in., for safety.

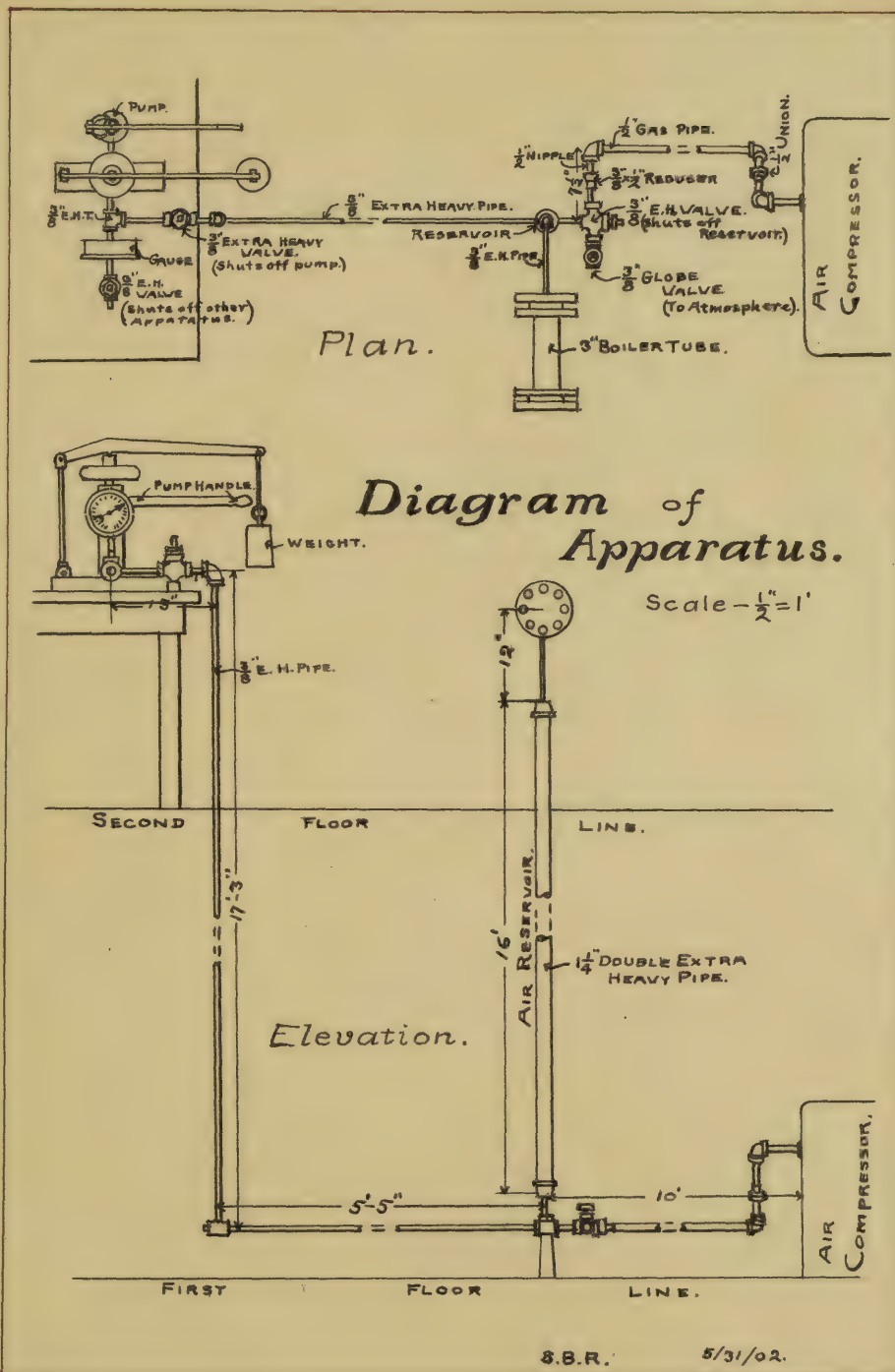
In making the reservoir of wrought iron pipe of length fifteen feet, the necessary internal diameter $= 2\sqrt{\frac{100}{15 \times 12 \times \pi}} = .84$ inches. For this could be used

a $1\frac{1}{4}$ " double extra heavy or a 1" extra heavy pipe (See Kent p. 196) but as the stress in the 1" pipe would be 10400 lbs per sq. in., without taking the weld into

account, which would probably increase this stress by 20% or more, the $1\frac{1}{4}$ " pipe was used; the stress in it being $= 4560$ lbs. per sq. in. (neglecting the weld.) Undoubtedly, under 4000 lbs. pressure the water in the reservoir absorbs a considerable quantity of air which it cannot hold at atmospheric pressure, as is seen from the milky appearance of the water when it is being drawn off from the reservoir under high pressure. This loss of air has probably been taken care of in the additional volume given to the reservoir.

To displace the air from the reservoir, it was desirable to introduce the water into the bottom of it, to insure that no water could enter the hot hot pipe, and the air compressor for filling the reservoir at 100 lbs. pressure should be

connected so that it could be shut off from the high pressure line and opened to the atmosphere, to insure that no water or air under high pressure could enter it. Therefore the arrangement of parts shown on the following page was adopted. The point of connection of the test piece was put at a considerable distance from the pump and pressure weighing apparatus to insure room for the heater, and also because this arrangement did not interfere with other apparatus on the first floor. From the pump, pressure weighing apparatus and Bourdon gauge the water is led through a $3/8$ " extra heavy wrought iron pipe to the bottom of the reservoir, which is capped at each end with steel "drum caps". The hydraulic valve which connects with



The air compressor is a three way valve which can only shut off the high pressure line from the compressor, while always leaving the compressor in communication with the $\frac{3}{4}$ " globe valve. The other hydraulic valves shown are simply screw down ones. By opening the three way hydraulic valve at the base of the reservoir and closing the globe valve, the reservoir may be pumped to 100 lb. pressure by the compressor. By then closing the three way valve and opening the globe valve, the air compressor is disconnected and water can be pumped into the bottom of the reservoir from the second floor, and the air forced up into the test piece until the desired pressure is obtained. The expansion of the test piece

into the ring of the header was first done by chucking the taper pin of the expander in the latter and holding the piece of boiler tube in the steady rest, two carpenter's clamps being clamped on the tube to form a stop against which to rest the ring into which the tube was being expanded. A stop of this kind to determine the position of the ring on the tube is always necessary, because if the ring is not correctly situated, either the end of the tube will project so far as to prevent the header from being put together, or it will not project far enough and so produce an excessive volume inside to be filled with high pressure air, as well as to prevent the tube from having the holding power that it might have if the

ring were correctly situated. One reason for using the lathe for expanding was that the internal diameters of the first rings into which the tube was to be expanded were a little too large for the tube, because the outside diameter of the tube was slightly less than the nominal size, and owing to this loose fit, it was difficult to start the expander by hand. Running the expander in the lathe, however, was found to be bad practice, as the amount that the tube is being expanded can be judged only by the amount by which the thickness of the tube has been decreased where the rollers of the expander have passed over it, also the tendency of the expander to work its way into the tube, instead of backing out, may make the removal of the expander a troublesome

operation. While using the expander in this way, one of the steel rings was actually stretched and thereby ruined. This practice is therefore to be avoided.

To determine the pressure that is actually necessary to push the header off of a 3" tube, several preliminary cold tests were made with hydraulic pressure, the test piece being full of water. In these tests, the results of which will be given later, the failure occurred by the tube leaking so badly in the expansion that the pump could not make up the leakage, or else, as usually occurred, the header was slipped along the tube about $\frac{1}{16}$ "; this, of course, immediately relieving the pressure since there was nothing but water in the system.

When it was found that one of the steel rings had been stretched and ruined by the expansion in the latter an attempt was made to substitute cast iron rings for the steel ones

because of the ease with which the cast iron ones could be made. The use of cast iron was detrimental in many ways. With the form of ring previously used, with a ridge $\frac{1}{8}$ " wide to make the joint on the copper gasket, this ridge, when of cast iron, would fail by compression. To prevent its crushing, the width of its base on one ring was doubled. This gave it sufficient strength at this part, but necessitated the widening of the groove in the cover plate of one header. When a steel ring was again substituted for the cast iron one, this modified form had to be given to it because the groove had been altered.

Before the very bad effect of expansion, in the latter was realized, one of the test pieces was expanded into a cast iron ring in the latter, and although the expansion was not excessive the ring cracked. This form of failure of the ring was not troublesome when the tube was

being expanded by hand but led to the abandonment of cast iron rings altogether after the first cold air test. In this test one header contained a cast iron ring and the other a steel one, the cast iron one being nearest the reservoir. The test piece had been expanded into the cast iron ring by hand, and owing to the test piece having been cut off very short, the steel plug could not be put in it and it was therefore poured full of plaster of Paris which had hardened fairly well before the test was made. At 2500 lbs. pressure, the header with the cast iron ring blew off of the tube with great violence, throwing the tube and other header a distance of about four feet and scattering the plaster of Paris in all directions. The necessity of preventing the headers from flying around in the way that they did was at once obvious, and the yokes and $1\frac{1}{4}$ " bolts shown in the section

through the header, were made to prevent the header from coming all the way off. The amount of energy stored up in the confined air under high pressure was now realized more perfectly than it had ever been before; it had been supposed that as soon as the header would start the linkage would at once relieve the pressure, causing a failure similar to that due to hydraulic pressure. The interesting point about this test concerning cast iron rings, is that the failure was caused entirely by the cast iron ring parting into three pieces, by tension, and allowing the tube to pull out of the header without bringing the outside diameter of the flared end of the tube down to the inside diameter of the rings. The flared end of the tube remained as large as ever, and had scarcely been rubbed by the cast iron ring. Evidently, as soon as the ring gave way, comparatively

little pressure was needed to force the pieces of the ring apart. Since the object of the experiment was to determine the holding power of expanded boiler tubes and not to investigate the strength of heads, the cast iron ring was abandoned, because what had been tested was really the strength of this particular form of ring, and not the holding power of the tube. A stronger ring was evidently needed and a new steel one was made.

For some time there had been a leak in the cast iron stand of the pressure weighing apparatus, due to the porosity of the casting, and since it had been found that a dangerous amount of energy was stored up in the highly compressed air, and since this porous cast iron was liable to fail, the weighing apparatus was boxed in with 2" planks to prevent the pieces from flying if the cast iron should give way.

In all the tests thus far made, the pressure was determined by means of the pressure weighing apparatus. In this contrivance a plunger of .255 sq. inches area worked through a stuffing box containing flake graphite and oil only. On top of the plunger was mounted a heavy flywheel about 7" in diameter and on this rested a block which supported weights hung on the end of a lever. Ball bearings were interposed between the block and the wheel so that the latter might be whirled around while the pressure was on, and thus eliminate the effect of friction on the plunger. By noting the weight hung on the lever the pressure in the system could be determined.

In order to do this, the different parts had to be weighed and measured. The results were as follows:—

Weight of plunger due to lever arm (found by putting scale pan under the lever in position):— 9 lbs $14 \frac{5}{8}$ oz

Weight of plunger: " $\frac{9}{16}$ oz



Pump, Pressure Weighing Apparatus and Bourdon Gauge.

Weight of flywheel 12 lbs. $15\frac{4}{16}$ oz

Total weight of parts on plunger 23 lbs. $14\frac{1}{16}$ oz

Area of plunger .255 sq. inch. (Diam = .57")

Pressure due to above weights = $\frac{23 \text{ lbs } 14\frac{1}{16} \text{ oz}}{.255} = 93.6$
lbs per square inch.

Ratio of lever arms 5:1, which causes the weights added at the end of the lever to produce a pressure of $\frac{5}{.255}$ or 19.6 times their own weight: — ($P = \frac{5W}{A}$)

Then we have — Pressure per sq. in. =

Weight added $\times 19.6 + 93.6$

The weights were added in a bucket weighing 3.06 lbs.

Therefore, pressure = (Wt. added + 3.06) $19.6 + 93.6$

$$\frac{P}{19.6} = W + 3.06 + \frac{93.6}{19.6}$$

So W, the weight to add, = $\frac{P}{19.6} - \frac{93.6}{19.6} - 3.06$

$$\text{or } W = \frac{P}{19.6} - 7.86$$

This gives the weight to be added to the bucket to obtain any desired pressure.

However, this method of determining pressures

was inconvenient, in that the exact breaking pressure could not be obtained, it being known only that it was between the last pressure attempted and the one next below it.

To obtain more accurate results it was determined to use a pressure gauge. For this purpose a heavy direct reading Bourdon gauge was purchased, calibrated by fifth lb. steps, up to 4000 lbs. per sq. inch. In order to be sure that its readings were correct, a calibration was made by means of the above described pressure weighing apparatus. They were found to agree very closely, and then the arm of the lever was fastened down with wire.

An important precaution to take before attempting to use high temperatures, was to be sure that no water passed over into the heated parts, which would probably cause an explosion. The only way to be sure of this appeared to be to weigh the amount of water pumped into the

reservoir during a test, and not allowing this to be greater than say 75% of the total capacity of the system. With this idea in view, a number of determinations of the capacity were made, by pumping in water until the system appeared full, and recording the weight of water pumped. The average weight of water at 76°F . which it required to apparently fill the system was 5 lbs. 7 oz. at atmospheric pressure.

In the next test that was made, careful account of the water pumped in was kept, but long before the pressure desired was attained this quantity far exceeded the apparent total capacity before determined. The cause of this discrepancy was ascribed to air trapped in the pipes, elbows, valves etc. In fact it was found to be the case that whenever the pressure was relieved at the upper end, a large quantity of air would rush out before the water, showing that the trapped air rose to the

top. As it was not possible to know how much air was trapped, or when it had been all removed, this method of ascertaining the water level in the reservoir was abandoned, and the action of the pressure gauge relied upon to indicate that there was still air in the reservoir.

Up to this time, the idea had been to raise the pressure until the head was blown off, but after the explosion before mentioned, it was determined to raise the pressure to only 2000 lbs, and if this was found to hold, it would be safe to assume a factor of safety of ten or 20. lbs. press. in.

The next difficulty encountered was the fact that the heads were found to hold on with great strength, but a small amount of leakage frequently took place around the expansion joint, due to pits and scale on the tube surface. Reexpansion was tried again and again, but it was, for a long time, impossible to stop this leakage,

although when under water pressure it sometimes took the water considerable time to pass the joint and show on the outside.

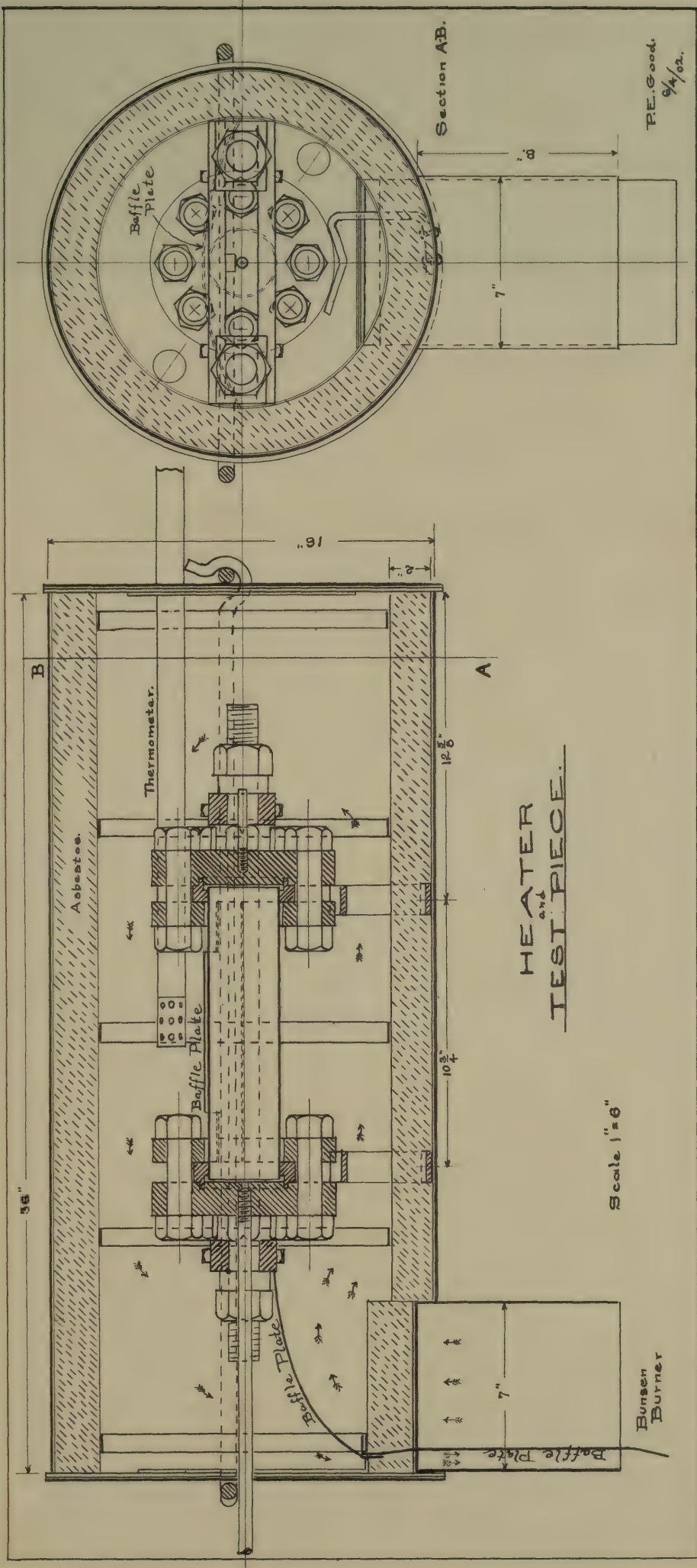
Of course this trifling leakage would not make any difference in a water test, or even in a practical superheater, because it took place only at pressures above 1000 lbs.

However, the hot tests had to be made with air, and the slightest air leak would make it necessary to pump in more water, until there would be danger of getting water into the heated parts, with the consequent liability to explode.

To prevent this leakage it was decided to file the outside of the tube ends quite bright and smooth. This was done, and an absolutely tight joint at 2000 lbs. pressure was at last successfully attained.

When this had been accomplished nothing was left to prevent the making of hot air tests, so attention was then directed towards the production of a satisfactory heater. For this

purpose a sample of 16" spirally welded steel
 steam pipe, three feet long was used. Sections
 were cut out for furnace and vent openings,
 and a rectangular furnace riveted on at the
 lower side of one end. Heads were also cut
 out of sheet steel and fastened on with an
 outside yoke. Two brackets were bent up
 from wrought iron, and riveted on the inside
 in such a manner as to support the test
 piece in a horizontal position parallel to
 the axis of the pipe. The whole thing was lined
 with asbestos plastered in in a wet condition to
 the thickness of two inches. Hoops were riveted
 to hold the lining in place. Several thicknesses
 of asbestos were riveted to each of the heads, and
 holes made for thermometers and pressure
 taps. The drawing of this apparatus gives
 a clear idea of its arrangement when assembled.
 The first plan for heating was to have the
 heat applied from the lower side of one end,



and then after passing around the test piece, to go out through the opening at the upper side of the other end. In order to obtain a high temperature it was found necessary to allow only a very slight draught, and if the air was shut off at the furnace end, the Bunsen burners used for heating gave great trouble by lighting inside the jets. Great attempts were made to stop the draught by closing down the exit opening. This caused poor circulation, and most of the heat came out at the furnace end, without reaching the test piece. When this was discovered it was decided to arrange baffle plates in such a manner that the heat would ascend to the test piece, pass around it and over it, and go out through a passage left in the furnace space. This was found to improve matters greatly, but there was



Heater Assembled.

still much discrepancy in the readings of the two thermometers. These were arranged, one on each side of the test piece, one somewhat above the other. The lower thermometer read about 200° below the other one. To remove this difficulty, another baffle plate was added, over the test piece, so as to cause the hot gases to travel further, before ascending and starting on their return journey. This final system of baffle plates worked so well that in the neighborhood of 1000° F. the difference in the readings of the two thermometers could be made as small as ten degrees. To attain this latter refinement, it was found necessary to slow the process of heating somewhat, by placing the Bunsen burner quite low down, so that the tops of the tubes were at least four inches below the bottom edge of the furnace sides;

care being taken to prevent the hot gases from interfering with those coming out the exit, by suitably screening the two currents.

Also, the gases inside the heater were made to follow the proper course by means of quantities of mineral wool placed in the cracks and spaces between the baffle plates, test piece and heater.

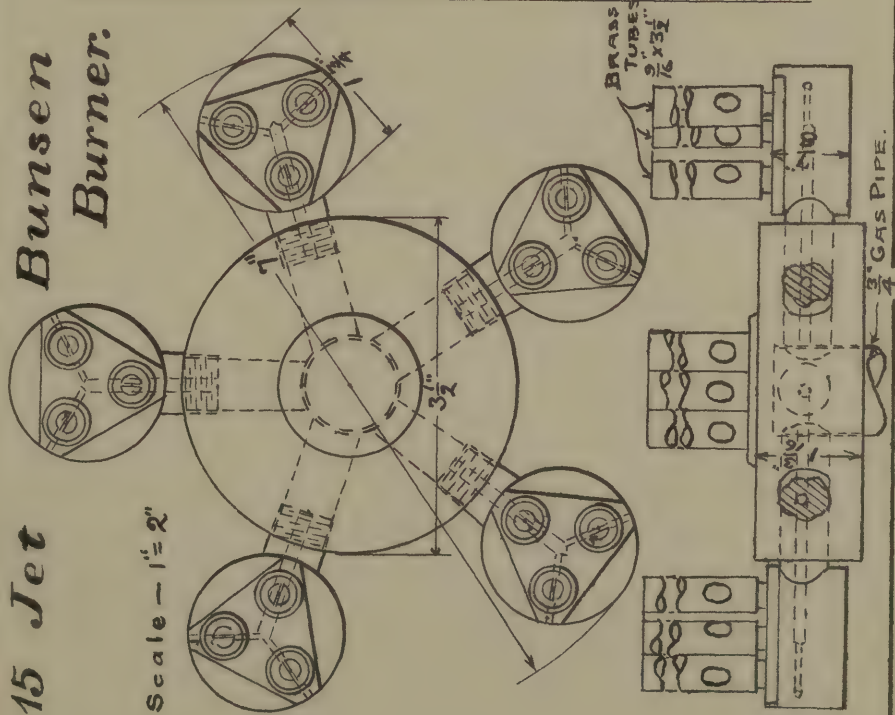
As before stated, the heat was supplied by means of a fifteen jet Bunsen burner.

This contrivance is shown in the drawing, which is its final form, differing from its original form only in the addition of the short lengths of $\frac{3}{16}$ " brass tubing at the jet, shown in detail in the right hand half of the drawing. These little tubes were hammered flat at their top ends so as to form a wedge shaped jet of gas which induced the draught of air in through the vents at the bottom of the larger tubes, thus producing a good

15 Jet

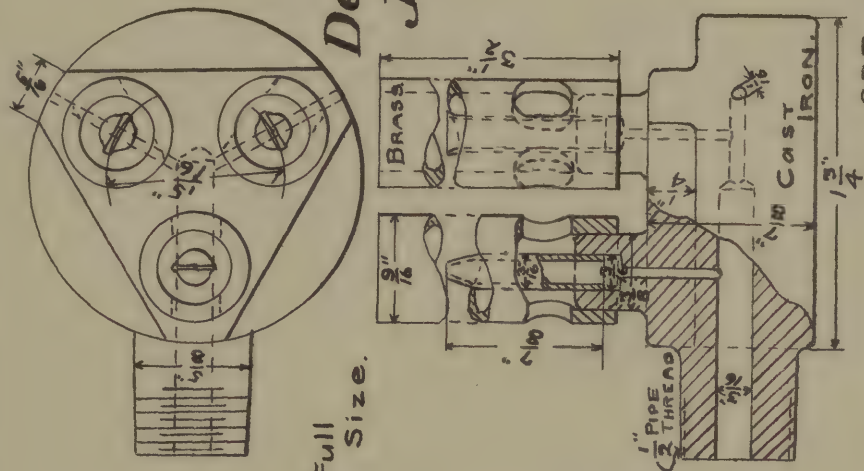
Bunsen Burner.

Scale - 1" = 2"



Full
Size.

Detail
of
Jet.



S.B.R. 4/1/02

mixture, and tending to prevent lighting at this lower point, which was always liable to occur before these jet tubes were put in. After considerable adjustment of these jet tubes, which were fastened in simply by a driving fit in a hole drilled as shown in the drawing, a fine blue flame was obtained, giving a great intensity of heat.

The jets were in groups of three, formed on the $1\frac{3}{4}$ " cast iron blocks. These were screwed into the central $3\frac{1}{2}$ " cast iron disk, which was provided with holes drilled to the center, where the gas was supplied by a $\frac{3}{4}$ " pipe. The outside diameter of the whole thing was about 7". The burner tubes were $\frac{7}{8}$ " brass, $3\frac{1}{2}$ " long; driven onto the projections on the cast iron blocks, forming the jets. The holes in these blocks were drilled in from the outside to

the center. Then after drilling downwards for the jets, the outer ends of two of the rods were plugged up with copper plugs, leaving open a passage from the secured neck to each jet, as shown in the drawings.

After starting the heater it was found that when a gas engine under test on the floor below was being run, the burners would all light at the lower openings, producing a yellow flame, and causing the temperature to drop. The interposition of a gas valve on the pipeline from the supply to the burner reduced this effect somewhat, but it was not possible to raise the temperature above 700°F when the engine was running.

Some practice was found necessary in the matter of assembling the heater and test piece in position for a test. The method finally used was however, very simple and it might be well to describe it. In

the first place the heater was rested in place on its supports in front of the reservoir connection. The connecting pipe was screwed into the test piece and passed into the end of the heater most remote from the reservoir, using the inside brackets to rest the test piece on while changing positions. Then, reaching in through the reservoir end of the heater, the end of test piece was lifted by means of the pipe and, one operator being at each end, the whole thing was raised and put in position on the brackets. Next, the yokes were put on, and the yoke bolts with their nuts screwed up hard, then backed off one turn to allow for slipping of header if it should let go under test. After putting on the heater head next to the reservoir, the connecting pipe was finally screwed into the elbow on top of the reservoir. It then remained only to arrange the baffle

plates and mineral wool; clamp the heater heads tight, by means of the outside yoke; insert the thermometers, so that their bulb ends reached opposite the center of the test piece; arrange the burner and various screens to prevent outside draughts; and after lighting the burner, to raise the pressure to the desired point and start the test.

In order to start a new test without taking the apparatus apart to drain out the water, the following method was used. The atmosphere valve at the top of the system near the pump was slowly opened and as much water as possible, was forced out by the compressed air in the reservoir. Then, to get all the remaining water out, the top valves were shut, also the atmosphere valve at the bottom, and air was forced in from the compressor at about 80 lbs per sq. in. Then the bottom reservoir valve

was shut and the compressor tank allowed to exhaust through the $\frac{3}{8}$ " atmosphere valve. Finally the bottom reservoir valve and atmosphere valve were opened, and the water forced out by the air. By this means a new test could be started without disturbing any of the heads, baffle plates etc, thus saving much time.

The tubes tested were 2.98" average external diameter, and .134" thick. The lengths varied from ten to twelve inches.

The first tests were with cold water pressure, leading to cold air, and finally to hot air tests. The record of tests is as follows:—

— Test 1 —

Cold water pressure. Failed by leakage at the expansion, without slipping, at about 1850 lbs per sq. inch.

— Test 2 —

Reexpanded same tube without cutting

off. End forced off at about 3300 lbs pressure per sq. inch.

— Test 3 —

Cut off No 2. Reexpanded. End forced off at about 2600 lbs per sq. in.

— Test 4 —

Cut off No. 3. Reexpanded. Head forced off at about 2600 lbs. per sq. in.

In the above tests the tubes were expanded in the lathe. All the failures took place at the same end, and the ring into which the tubes were expanded became much stretched and very smooth, so that its holding power was much reduced.

— Test 5 —

A cast iron ring was used in place of the worn out steel one, and hand expansion resorted to.

This time it leaked badly at the expansion joint at about 2300 lbs. per sq. in.



This was reexpanded without cutting off. Head then forced off at about 2700 lbs per sq. in. pressure. This was due to the bursting of the cast iron ring. In the last part of this test cold air pressure was used and the explosion took place as before described.

—Test 6.—

Bourdon gauge obtained. Pressure limited to 2000 lbs per sq. in. New cast iron ring used. Burst at 1500 lbs per sq. in. Cast iron abandoned.

—Test 7—

New steel ring used in place of cast iron one. Leaked under 500 lbs cold water pressure at expansion joint.

Reexpanded - Leaked at 1000 lbs.

Reexpanded - tight at 1000 but leaked at 1500 lbs.

Reexpanded - leaked at 2000 lbs cold water

pressure. This tube abandoned.

— Test 8 —

Ends of tube smoothed off with a file. Seaked on the new ring end in the expansion, at 2000 lb. cold water pressure. Reexpanded this end. Tight for ten minutes at 2000 lb. cold water pressure. Tested with cold air. Attempted to weigh the water pumped in as before described, with the results before mentioned. Leak discovered on reexpanded end but pressure kept up well, showing air to be still present in the reservoir.

Removed and replaced without altering. Found to be tight at 2000 lb. air pressure after lying idle several days.

Heated to about 800°F . without any pressure. The thermometers differed by about 200° . When cold again, one gasket leaked. This copper gasket replaced by annealed steel one. Tight at 2000 lb. cold. Baffle plates put in as described and heated to 1000°F .

without pressure.

Tested cold (with air) and leaked in copper gasket. This gasket replaced twice by iron ones, which both leaked, as did also the expansion joint at 200 lbs cold water pressure.

— Test 9 —

Cut off No. 8. Tube end filed smooth and reexpanded. Copper gasket put in this end. Tight at 200 lbs cold water & cold air pressure.

Pressure set at 200 lbs per sq. in. and temperature raised to 500°F on upper thermometer and 450° on the other. Found to remain tight at this pressure and temperature.

Cooled down and found to be tight under 650 lbs. cold air pressure.

— Test 10 —

Another baffle plate added, over the

test piece, as before described, and pressure maintained at 650 lbs., while temperature was raised until thermometers read 1000°F and 990°F . respectively. Found to be tight under these circumstances.

Cooled down and pressure raised to 1100 lbs., cold air. Leak suspected by sound.

— Test 11 —

Pressure maintained at 1100 lbs. and temperature raised.

Considerable leakage, probably in gasket.

Redrained and pressure again raised without cooling.

This repeated at a temperature of about 600°F and again at 800°F

Leak appeared to decrease, and when upper thermometer read 1000°F , and lower one 980°F , it was found to be perfectly tight under 1100 lbs pressure.

This showed that copper gasket grew tight, due to expansion on heating.

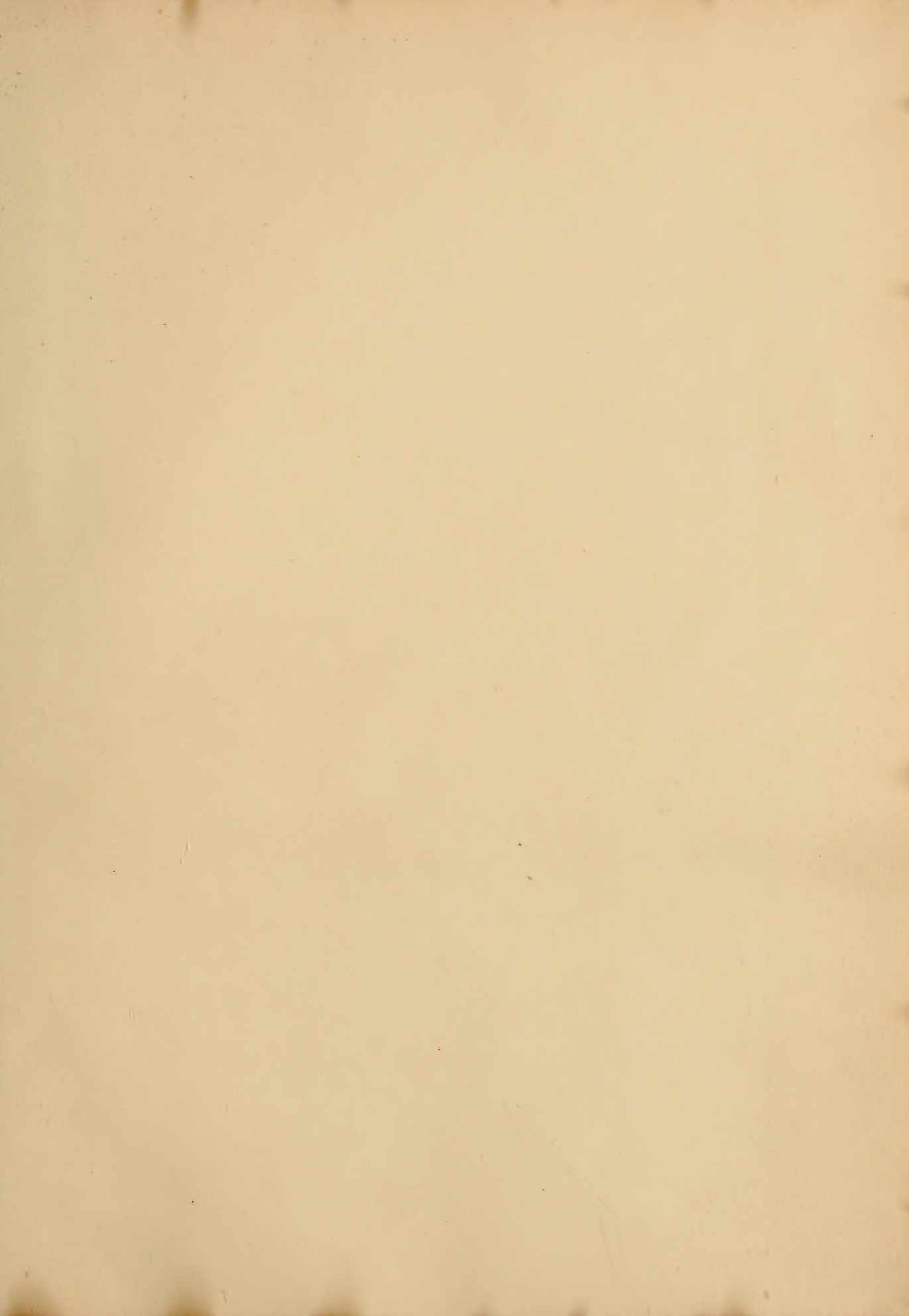
As time was growing short, this investigation was not carried further, but as far as can be seen, temperature has no effect on the holding power of an expansion tube joint, up to the limit of 1000°F and 11.00 lbs pressure per sq. inch.

In all these tests, the main fault was in leakage, which would not develop under ordinary pressures. Every tube which was tested, except those that in which the cast iron ring burst, was found to hold at 2000 lbs per sq. inch. cold, giving a factor of safety of 10 on 200 lbs.

In the first tests careful measurements of the tube diameter were made under various pressures, which went to show that the enlargement of the tube under

as much as 3000 lbs per sq in. was not measurable with an ordinary caliper.

When the tubes were expanded sufficiently to be tight at 2000 lbs pressure, the taper mandrel of the expander was found to drive down solid, and a considerable ridge was produced on the inside of the tube.



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